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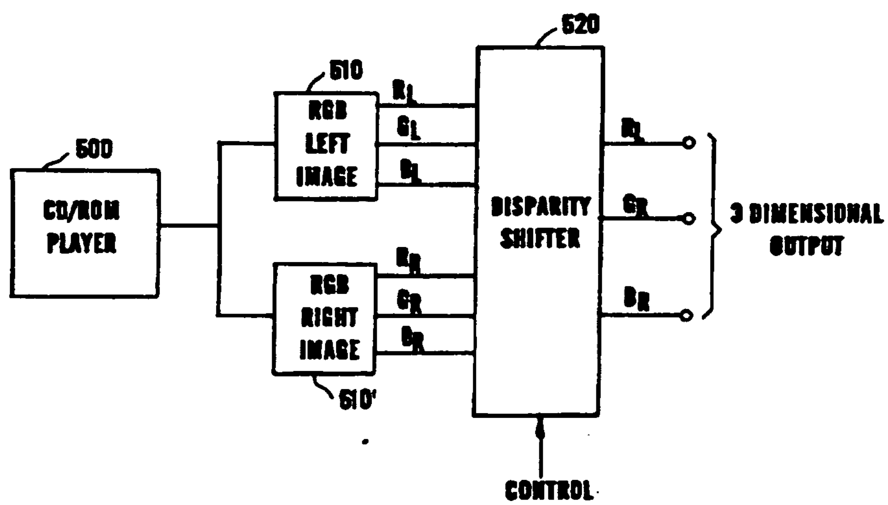


(57) Abstract

In the capture and display of three dimensional images, techniques are provided for controlling the amount of disparity between left and right images used to create a three dimensional representation to permit three dimensional perception which would otherwise be lost as dispartiy increased beyond psychological and physiological limits. Both mechanical (470) and electronic means (520) for controlling disparity are shown. Techniques are disclosed for creating three dimensional animations which utilize disparity control for adjusting the perceived depth of an object vis-a-vis a neutral plane. When zooming in on an object with a stereo camera pair, the shift is in focal length accompanying the zoom is accompanied by a simultaneous shift in disparity so that the stereo effect it not lost when a target object is very close, a moderate distance, or very far from the cameras.

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# METHODS AND APPARATUS FOR ZOOMING DURING CAPTURE AND REPRODUCTION OF 3-DIMENSIONAL IMAGES

## CROSS REFERENCE TO RELATED APPLICATIONS:

This is a Continuation-in-Part of Application Serial No. 08/339,156 which was filed November 10, 1994 by inventors Charles S. Palm and Raymond McLaine.

This application is a continuation in part of application Serial No. 08/335,381 by the same inventors, filed November 3, 1994, titled **METHOD AND APPARATUS FOR THE CREATION AND TRANSMISSION OF 3-DIMENSIONAL IMAGES** (Docket No. 2345-002), the contents of which are hereby incorporated by reference.

This application is also related to application Serial No. 08/318,047, filed October 10, 1994, titled **METHOD AND APPARATUS FOR INTERACTIVE IMAGE CORRELATION FOR THREE DIMENSIONAL IMAGE PRODUCTION** (Docket No. 2345-001) the contents of which are hereby incorporated by reference.

This application is also related to application Serial No. 08/327,471, filed October 21, 1994, titled **METHODS AND APPARATUS FOR RAPIDLY RENDERING PHOTO-REALISTIC SURFACE ON 3-DIMENSIONAL WIRE FRAMES AUTOMATICALLY** (Docket No. 2345-003) the contents of which are hereby incorporated by reference.

## BACKGROUND OF THE INVENTION:

When capturing and reproducing 3-dimensional images in the prior art, information from one camera of a stereo pair of cameras was depicted as one color (e.g. orange) or band of colors and information from the other camera of the pair was depicted in a complimentary color or color band. When viewing such images through 3-dimensional viewers, such as red/blue glasses, the reproduced image would not be perceived in color.

The orange elements in the picture are only seen through the blue lens, the red lens "washing out" the orange elements. For the same reason, the green-blue elements are only seen through the red lens. Hence, each eye sees only one of the two colored pictures. But because the different colored elements are horizontally shifted in varying amounts, the viewer's eyes must turn inward to properly view some elements, and turn outward to properly view others. Those elements for which the eyes turn inward, which is what the viewer does to observe a close object, are naturally perceived as close to the viewer. Elements for which the viewer's eyes turn outward are correspondingly perceived as distant. Specifically, if the blue lens covers the viewer's right eye, as is generally conventional, then any blue-green element shifted to the left of its corresponding orange element appears to the viewer as close. The element appears closer the greater the leftward shift. Conversely, as a green-blue element is shifted only slightly leftward, not at all, or even to the right of its corresponding red element, that element will appear increasingly more distant from the viewer.

The above mentioned co-pending applications teach techniques for producing color 3-dimensional images.

When 3-dimensional images are captured, corresponding points of the left image are displaced from the same points in the right image horizontally. A

measurement of the amount of displacement is called "disparity". In the prior art when stereo images are made, the disparity for all subject matter visible in both images is fixed. In digital images, disparity can be measured in terms of the number of pixels an object is displaced in the right image relative to its position in the left image. Fixed focal length lenses are customarily used for the cameras

In an object with zero disparity, the corresponding pixels for the left and right images are perfectly superimposed and the object appears to be located on the screen. Zero disparity objects are seen most clearly when the eyes are crossed just enough to focus on the plane of the screen. Negative disparity objects appear to come out of screen toward the viewer and are seen most clearly when the eyes are more crossed. Positive disparity objects appear to be more distant than the screen and are seen most clearly when the eyes are less crossed.

The eyes cross or uncross in order to get similar image features on or near the fovea of each eye. The "farthest" object that can be seen in an anaglyph is limited by the observers ability to comfortably uncross the eyes. (The usual limit to distant viewing is set by the condition where the eyes look along parallel axes, but such "wall-eyed" condition is rarely comfortable to the observer.)

In an anaglyph, the disparity for all objects is fixed and is measured in terms of pixels of displacement. When one "zooms-in" on a computer image to see more detail, the pixels get larger and the center-to-center spacing between pixels becomes larger. Therefore, constant disparity (measured in pixels) image components become physically farther apart on the screen. In order for the human visual system to fuse image components and produce the sensation of true stereo vision the eyes have

to uncross more for each step of "zoom-in". Eventually, the physical separation between corresponding image components becomes so great that the eyes cannot "uncross" comfortably any more (wall-eyed condition) and stereo depth is lost to the observer.

Some stereo images cover such a great range of depth and will have such widely varying values (even without a "zoom-in") that some portions of the image will always be out of range of the observer's ability to see the stereo effects, regardless of how the anaglyph was formed.

Three dimensional techniques are closely related to the psychology and physiology of an observer's cognitive processes. Subtle changes in selection of portions of the spectrum presented to each eye can result in significant changes in the observer's perception. Even when viewing the same 3-dimensional image through the same viewers, different observers may perceive a 3-dimensional image in different ways.

The depth location of the point at which the left and right image points for objects at that distance coincided constitutes a "neutral plane" and when observing a fixed disparity 3-dimensional image, the neutral plane would be found at the surface of the medium of reproduction (i.e. paper or CRT display). Items that appear closer than the medium surface and those points in the image which appear behind the neutral plane would have different disparity. The loss of depth perception when disparity exceeds a certain value generally means that when zooming-in on part of a stereo image pair that disparity will become so great that depth perception will be lost. This is a serious drawback when, for example, attempting to use medical images captured in stereo for instructional purposes. Typically, one would need to examine parts of an object in detail by going close up. This problem is analogous to having a fixed focal length

microscope and being unable to see close up features which do not lie directly in the focal plane.

Also in the prior art, when capturing 3-dimensional images on film, magnetic tape or the like, there is no way to visually monitor the combined impact of the separate images being captured. As a result there is no way of adjusting disparity or automatically tracking an object and adjusting disparity automatically.

In the prior art, there is no way to control an image so as to position it either in front of or behind a neutral plane in a controllable fashion. This limits the ability to create 3-dimensional animations.

Also in the prior art, there was no way to adjust the views of 3-dimensional images captured on a static medium, such as CD/ROM.

In the prior art, when viewing stereo images, particularly for extended periods of time, viewers experience a certain amount of discomfort, such as eye strain and headaches. It would be desirable to minimize or eliminate such discomfort.

In the process of zooming in upon an object using stereo cameras, to avoid a loss of stereo effect as disparity exceeds the limits of the human mind to fuse the two images together into a 3-dimensional view, in the prior art cameras were "toed in" toward the object being zoomed upon. The inventors have recognized that this produces certain undesirable results which should be avoided.

When using cameras fixed as to separation and orientation, for scenes that are too far away there may be too little and for scenes too close there may be too much disparity leading to a loss of stereo effect. This, too, is undesirable.

The prior art lacked the ability to zoom-in on portions of a scene when capturing the scene from one location. In order to zoom-in on a scene in the prior

art, a stereo camera pair with fixed focal length had to be physically relocated closer to the object being captured.

## DISCLOSURE OF THE INVENTION:

One advantage of the invention is that it allows for controlling disparity when capturing or reproducing an image.

Another advantage of the invention is that it permits a user to control the disparity by which left and right images are separated.

Another advantage of the invention is the simultaneous adjustment of focal length in stereo camera pairs.

Another advantage of the invention is the ability to adjust camera separation or camera toe-in.

Another advantage of the invention is that it permits zooming-in on portions of a stereo image without losing depth perception.

Another advantage of the invention is the ability to control the location of the neutral plane in 3-dimensional views, thus enabling objects to be controllably placed in front of the neutral plane (popping out of the screen) or behind the neutral plane (in background).

Another advantage of the invention is the ability to create a computer animation using disparity control to produce very realistic animations which move in front of and behind the neutral plane.

Another advantage of the invention is a reduction in the amount of personal discomfort experienced when viewing stereo images. The inventors have discovered that the amount of vertical shift between corresponding points on left and right images can cause discomfort such as eye strain and headaches as one eye tries to move

upward vis-a-vis the other to fuse the corresponding points into a stereo image.

Another advantage of the invention is that cameras can be maintained in a parallel orientation without undesirable vertical shift caused by "toe in" of two cameras in an attempt to compensate for exceeding the disparity limits tolerated by the human brain for fusing a stereo image.

Another advantage of the invention has to do with preventing the loss of stereo effect when distances are so far that there is too little disparity for the stereo effect or are too close so that there is too much disparity for the stereo effect.

These and other objects and advantages of the invention are achieved by providing methods and apparatus for viewing three dimensional images which shift one image view with respect to an other image view to control the amount of disparity between corresponding points of the two views and displays the image views so as to form a three dimensional image. The shifting of one image view with respect to another is accomplished by cropping two image planes at different ends by the amount of a desired disparity shift and then combining the cropped image planes to produce a three dimensional display. The shifting can also be accomplished by limiting the read out of certain addresses of each line of video memory image information using a shift register to receiving a line of image data and selecting which cell of the shift register is used for shifting the contents of the shift register to an output.

The invention is also directed to apparatus for capturing and storing three dimensional images using a left camera and a right camera, each with a zoom lens. The zoom lenses are controlled so that each camera zooms substantially identical amounts when zooming is used.

The invention also relates to apparatus for mechanically controlling disparity of images captured by two different cameras, and storing those images. One camera is movably mounted for controlled movement with respect to the other, such as toe-in or horizontal offset.

The invention is further directed to an apparatus for zooming on a scene using a three dimensional camera arrangement with each camera having a zoom lens. The zoom lenses are controlled with servomechanism so that each zoom lens zooms the same amount. A number of coding indications may be used to control the amount of zoom.

The inventions is further directed to apparatus for producing three dimensional images captured using a left and a right video camera connected to respective left and right video recorders. Images from the left and right video recorders are synchronized with each other. The output of the left video recorder is filtered to eliminate blue and green information and the output of the right video recorder is filtered to eliminate the red information. The two outputs are combined to produce a three dimensional image.

The inventions is also directed to reproducing a three dimensional image from first and second digital images stored on a storage medium such as CD/ROM. The first and second digital images are both decomposed into red, green and blue color planes. One color plane of the first digital image is shifted with respect to other color planes of said second digital image and the shifted color plane of the first digital image is combined with the other color planes to produce a three dimensional image.

The invention also contemplates a method of live monitoring of three dimensional images being captured by first and second cameras to a storage medium separating the output of each camera into color planes, combining

one color plane of said first camera with one or more different color planes from said second camera; and by displaying the combined color planes.

The invention also contemplates a method of automatically adjusting an image parameter such as disparity during creation of a reproduction of a live scene by placing a small, highly reflective material on a target to be tracked, illuminating said highly reflective material, using the bright spot created by reflection from said highly reflective material for calculating target position and by adjusting said image parameter based on the calculated target position. The image parameter can also be focus or zoom.

The invention is also directed to a method of moving the apparent position of an object represented as left and right images which together constitute a three dimensional image viewed by a viewer to make the object appear to move toward the viewer or recede away from the viewer by shifting the position of the left and right images to change the disparity between the left and right images to thereby cause the perceived relative positions of the object to move

The invention also permits creating a three dimensional computer generated animation of an object by representing said object as a three dimensional wire frame, rendering a surface on said wireframe, creating two color perspective views of said rendered wireframe, separating each of said two color perspective views of said rendered wireframe into 3 color planes, combining one color plane from one of said views with two other color planes from the other view, storing the combined color planes as a three dimensional image, moving said object by modifying said wire frame; and repeating the steps for as many iterations as desired and then displaying sequentially each three dimensional images stored as a three dimensional animation.

In one aspect, the invention is directed to apparatus for capturing three dimensional stereo images of a scene using a left camera and a right camera with parallel optical axes and with a mechanism for maintaining spacing between the cameras at a fixed fraction of a distance to a targeted object. The fixed fraction is a default value which can be overridden by manual adjustment.

The invention is also directed to apparatus for capturing three dimensional stereo images of a scene using a left camera and a right camera with substantially parallel optical axes, and substantially identical zoom lenses. Disparity is adjusted while adjusting focal length of the zoom lenses to hold a location of the neutral plane substantially constant and/or to avoid loss of stereo effect.

The invention is also directed to a method of maintaining disparity of a stereo pair of images within a range which avoids a loss of stereo effect without camera toe in while avoiding vertical shift between corresponding points of a left view and a right view of said stereo pair by maintaining the optical axes of a left camera and of a right camera substantially parallel, and by adjusting disparity while adjusting distance to a target object to avoid loss of stereo effect.

Still other objects and advantages of the present invention will become readily apparent to those skilled in the art from the following detailed description, wherein only the preferred embodiment of the invention is shown and described, simply by way of illustration of the best mode contemplated of carrying out the invention. As will be realized, the invention is capable of other and different embodiments, and its several details are capable of modifications in various obvious respects all without departing from the invention. Accordingly, the

drawings and description are to be regarded as illustrative in nature and not as restrictive.

**BRIEF DESCRIPTION OF THE DRAWINGS:**

Figure 1 is an illustration of disparity variations as a function of distance from the neutral plane.

Figure 2 shows the cropping of two image planes to vary the amount of disparity.

Figure 3 illustrates two cameras used for capturing 3-dimensional images which are adjustable to control tow-in or horizontal displacement from each other.

Figure 4 shows two cameras for capturing 3-dimensional images which have zoom lenses control simultaneously.

Figure 5 shows disparity adjustment when displaying right and left static images from a storage medium.

Figure 6 illustrates a disparity shifter which utilizes address displacement.

Figure 7 illustrates another disparity shifter which utilizes a shift register output for selectable output tabs for controlling the cropping of images retrieved from storage.

Figure 8 illustrates methods and apparatus for the capture and reproduction of 3-dimensional images utilizing video cassette recorders.

Figure 9 is a flow chart of how to make a three dimensional computer generated animation.

Figure 10 is an illustration of how camera tilt produces vertical shift in points which would otherwise be at the same vertical position.

Figure 11 illustrates the disparity problem resulting from points being different distances from an optical axis and how distance between cameras should be adjusted as a function of target distance in most situations and how disparity should be adjusted concurrently with a change in focal length.

**BEST MODE FOR CARRYING OUT THE INVENTION:**

The invention is based in part upon the inventors' realization that, when viewing 3-dimensional images, a loss of depth perception ensued when zooming-in on portions of the image. Subsequent work indicated that many of the problems related to the issue of disparity. As noted above, disparity is a measure of the amount of displacement between corresponding points of an image presented to the left eye via a vis points on an image presented to the right eye. This is illustrated in Figure 1.

In Figure 1, a neutral plane is defined as running through point B. Point A is located behind the neutral plane and point C is located in front of the neutral plane when viewed from focal points 100 and 100'. The projection of points A, B and C through the respective focal points onto focal planes 110 and 110' results in points $A_L$, $B_L$, $C_L$, $A_R$, $B_R$ and $C_R$. Focal planes 110 and 110' are shown transposed so as to be vertically disposed with respect to each other. The distance between the image of points A, B and C on the left image plane and points A, B and C on the right image plane are illustrated. The measure of the distances A, B and C shown beneath the vertically aligned focal planes is measure of the disparity. As can be seen in Figure 1, the further a point is from the neutral plane, the greater the disparity is.

At some point, the disparity becomes so great that a viewer is incapable of recognizing the depth information and fusing the two images into a single 3-dimensional view. As a point regresses further behind the neutral plane, the angular difference between points separated by a unit distance becomes progressively less and so a big difference in depth will result in a smaller angular displacement on the focal planes on which points far behind the neutral plane are projected. This results

in a loss of depth detail at far distances behind the neutral plane.

The inventors have discovered that both of these problems can be overcome by allowing the user to control or adjust the amount of disparity between corresponding points on the two image planes. This principle is applicable to all stereo viewing systems and not just to those using color viewers.

For example, if distance B shown at the bottom of Figure 1 represents the amount of disparity at a neutral plane, and if the amount of disparity shown at C was so great as to result in a loss of depth perception, depth perception can be restored by shifting image plane 110 vis-a-vis image plane 110' so that the distance C between corresponding points is reduced to that of distance B, i.e. to a position on the neutral plane.

Figure 2 shows at a high level how this may be done. Figure 2 illustrates two color video images 200L and 200R which were captured by left and right digital cameras, such as video cameras or digital still cameras. In creating three dimensional images, it is convenient to utilize, as set forth in the above patent application (Docket No. 2345-002) separation of left and right images into color planes as shown. Image 200L constitutes the red color plane from the left camera and 200R constitutes the blue and green color planes from the right camera. When combined, into a three color plane representation, three dimensional images are produced and are viewable using standard red-blue viewers. This particular technique preserves color information as indicated in the aforesaid co-pending application. As shown in Figure 2, the left and right views of point X are located 30 and 40 pixels displaced from the left edge of the image as indicated. There is thus a 10 pixel disparity between the position of the left and right points. By shifting the color planes so that the image 200R is displaced 5

pixels to the left and by shifting the image 200L 5 pixels to the right, the two views of point X will exactly coincide or, in other words, point X will lie in the neutral plane when viewed. Figure 2 illustrates that the shifting is accomplished by truncating the image by 5 pixels on the left side of image 200R and by 5 pixels on the right side of 200L. Although not required, this is done because some image processing packages require that both images be of the same size in order to combine them.

Disparity adjustment may occur manually. Figure 3 illustrates two different ways in which disparity adjustment can occur.

Disparity can be adjusted by changing the toe-in angle between the two cameras 300 and 300'. Each camera is illustrated as being mounted on a pivot point 320 or 320' and the angular orientation of a camera is adjusted by screwdrive 330 which moves the rear end of the camera vis-a-vis points 335A and 335B. Even if this were not required for disparity adjustment, it would be a useful mounting for ensuring parallel alignment of the two cameras.

The other method involves changing the separation of the cameras 300 and 300' by moving one with respect to the other along rails 340 and 340'. As shown in the left hand view of Figure 3, the inner part of rail of 340' has teeth 345 which constitute part of a rack-and-pinion drive. The pinion 360 is driven by servo motor 350 to permit the entire platform to move vis-a-vis the other camera.

In the prior art, three dimensional cameras utilized fixed focal length lenses. That is, the focal length could not vary to permit a zooming function. This is somewhat inflexible since in standard movie or video making, zooming is a very convenient tool for the camera man. If one image of a stereo image pair were larger

than the other by virtue of different settings of a zoom lens, image offsets would occur which would interfere with human perception of depth, and thus the stereoscopic effect would be lost.

Figure 4 illustrates one mechanism for permitting zoom lenses to zoom in synchronism so that the integrity of the three dimensional resulting image is preserved. Cameras 400 and 400′ are each equipped with zoom lenses 410 and 410′, respectively. A cross member 420 engages both lenses 410 and 410′ in such a way that motion imparted to one is also imparted to the other. Member 420 is driven by either a rack-and-pinion driven arm 430 or by a screw mechanism utilizing servo motor 440 with optional gearbox 450. Thus, when the arm 430 is displaced by the servo motor, zoom lenses 410 and 410′ move in synchronism in and out depending on the direction of actuation.

Individual stepping motors can be used to control the zooming of individual lenses. One lens is the master, the other the slave. A combination look up table tells the slave how many steps to move relative to the movement of the master.

Figure 5 illustrates an arrangement for displaying three dimensional images which have been stored in storage such as a CD ROM. CD ROM player 500 serves left and right images of a stereo image pair. These are read into respective left and right image buffers 510 and 510′. The images are stored and the image buffers accommodate full color images, typically in 24-bit format with 8 bits of each format constituting, for example, red, green and blue image planes. Image buffers 510 and 510′ output their respective image planes to disparity shifter 520. Disparity shifter 520 is described in more detail hereinafter. Again, in keeping with the disclosure of the aforesaid co-pending patent application, the red image plane of the left image is

combined with the green and blue image planes of the right image to produce a composite three dimensional image. Disparity shifter 520 allows the left and right image planes to be shifted relative to each other.

Figure 6 illustrates one form of disparity shifter utilizable with the arrangement of Figure 5. Random access memory 600 and 600' may either be the actual image storage 510 and 510' of the previous figure or, when live digital images are being received, may constitute separate video RAMS. Once an image is stored in each RAM 600, the data may be read out using X and Y decoders 610, 610' and 620. An address source 630 feeds both the X and Y decoders. A register 640, contains the number "n" which indicates the amount of disparity shift desired for the image plane. Control of the amount of disparity shift can be accomplished by simply changing the value of the variable "n" in register 640. Subtractor 650 and adder 660 respectively subtract and add the value "n" to the column addresses of the Y decoders. As the address source 630 sequences through each line, the columns at the beginning and end will be truncated as shown in Figure 2.

Figure 7 shows another method for disparity shifting. The output from video RAM is fed in parallel to a shift register and then the data is clocked to an output port for use. As shown in Figure 7 by selecting which output cell to take the output from when shifting the shift register's output content to the right one can effectively delete a number of pixels "n" from the output stream. Since this is done line by line the entire image will be truncated on the right end in the version shown. A value "n" is written in register 720 and that value causes decoder 730 to select one of the outputs indicated. Activation of one of those outputs causes one, and only one, of the and gates, illustrated as 740 through 743 to permit data from the connected cell of the

shift register to pass through to or gate 750 where it is passed to the output terminal. To truncate pixels from the other end of the RAM 700, one would add a number of additional shift register cells to the right of the last cell currently shown and utilize the selection gates and procedures described with reference to Figure 7. In this alternative, a number of shifting clock pulses will be utilized equal to the number of cells in the shift register. Since there are more cells in the shift register than there are clock pulses, the last few cells from the left end of the shift register will not be read out to the output of or gate 750. The shift register is reset prior to loading in the next line of data from RAM 700.

Figure 8 illustrates another approach to producing three dimensional images. Analog video cameras 800 and 800′ record full color images of a scene on VCRs 810 and 810′, respectively. When played back, the output of one of the VCRs is fed to a red filter 820 which extracts red information, and the output of the other VCR is fed to filter 830 which extracts blue/green information. The output of filters 820 and 830 are optionally brightened and combined in a frequency combiner such as an adder, and passed to output terminal 850. In the signal paths described thus far, there is no way for anyone to see the image in real time so as to determine the adequacy of the stereo production. Although a cameraman can view the scene being captured through the viewers of each of cameras 800 and 800′, those views are two dimensional. By using a three dimensional image maker, such as that disclosed in the aforesaid co-pending application, the color signals from each of the analog video are converted into individual color planes and the red color plane from the left camera is combined with the green and blue color planes from the right camera to produce a three dimensional image suitable for display on color cathode

ray tubes 870. When viewed through viewers, one can see in real time the three dimensional image produced by the camera pair 800 800'.

When capturing live scenes using apparatus such as shown in Figure 8, it is sometimes necessary to track the distance of an object or person from the cameras. One way of doing this is to place a small, highly reflective material, such as 3M reflective tape, on the target to be tracked. If that target is illuminated with a light source, a highly visible point on the target will appear in the captured image. One can utilize such bright spots created by reflection for calculating target position based on the position of the high intensity target on the screen. Typically, one would monitor the intensity value of the pixels and when a very intense pixel is identified, the address of the pixel would be captured and utilized in a calculation, such as that described in co-pending application (Docket No. 2345-001) to determine distance from the cameras to the target. This distance then can be utilized to establish a number of camera parameters such as focus, disparity or zoom.

The presence of such a bright pixel in the output image can be easily detected and removed by routine image processing techniques either on-line or in the post production suite.

Figure 9 is a flow chart of a method for creating three dimensional computer generated animations of an object. First, the object is represented as a three dimensional wire frame (900). Then a surface is rendered on the wire frame (905). Then, two color prospective views of said rendered wire frame are created, one from the position of a first camera and another from the position of a different camera (910). Each prospective view is separated into three color planes (915). Optionally, the disparity between the two views can be controlled so that the object pops out or moves behind

the neutral plane (920). One color plane from one of the views is combined with two different color planes from the other view and the combined color planes are stored as three dimensional images (930). The wire frame representation of the three dimensional object is then moved as desired incrementally (935) and steps 905 through 930 are repeated for as many iterations as desired (940). Once sets of three dimensional images are created in this manner, they may be displayed sequentially in rapid succession as part of a three dimensional animation.

Figure 10 illustrates a vertical shift which occurs when a view of an object is tilted with respect to the camera focal plane. Figure 10 shows a box ABCD and what happens when the planar surface of ABCD is viewed from an angle such as might occur when the camera focal plane is tilted with respect to the plane of the surface or, as illustrated, when the plane of the surface is tilted with respect to the focal plane. Tracing rays from points A and B through the focal point to the focal plane shows that the image of point B is closer to the center of the focal plane than the image of point A. Since side BD is farther away from the focal point than side AC, side BD appears smaller and size AC appears larger relatively. Thus points A and B which are the same height, appear to be different heights in the image plane.

Figure 10 shows only one projection but if the same square were projected from two different cameras both toeing in toward the object ABCD, the effect would be even more pronounced because point B on one image would be lower and the same point on the other image would be higher, thus creating a vertical shift between the same point in the left and right views of the stereo image. As the eye tries to adjust to this vertical shift, eye strain often results.

Techniques for compensating for vertical shift are discussed in application serial no. 08/481,993 filed June 7, 1995 (docket no. 2345-002A) by the same inventors hereof which application is hereby incorporated herein by reference in its entirety.

In accordance with the invention, the axes of the two stereo cameras are kept parallel. That is, there is no toe in to compensate for disparity adjustment. However, in accordance with the invention, to avoid a loss of stereo effect, it is preferred, as a matter of default settings that the distance between the cameras be a relatively fixed fraction of the distance to the target. Preferably, the distance between cameras might be approximately 1/50 of the distance to the target. This can be accomplished by linking the operation of servo 345 of Figure 3 which controls camera separation with an indication of distance to one target derived from a rangefinder or from autofocus circuitry. Control by a rangefinder or autofocus circuitry can be bypassed by selectively switching out its control signal and by replacing it with a manually generated one. With a 1/50 relationship, the distance will be neither too great nor too small so as to lose stereo effect. Further, it is desirable to arrange the disparity so that the target distance appears in the neutral plane. Figure 11 also illustrates that with the change in focal distance, there is a resulting change of scale. As shown in the left side of Figure 11, the image of line AB through focal point F1 under the focal plane has an extent $A_D$ which is smaller than the image of line AB through focal point F2 which occupies an extent $B_D$. As expected, the image size increases as focal length of the lens increases. Since line AB is centered on the optical axis of the left camera, the center of the image of line AB is at the same point for both settings of focal length, namely, it is located at the center of the image plane. However, the

image of line AB through focal point F1 of the right camera and focal point F2 of the right camera are considerably displaced from the axis of the camera. Specifically, the image of point C through focal point F2 of the right camera is off the focal plane as shown whereas image of point C through focal point F1 lies barely on the image plane of the right camera. In contrast, corresponding points on the left image plane are comfortably within in the bounds of the image plane.

According to Applicant's invention, when changing focal distance, it is desirable to simultaneously change the disparity to maintain the target in the neutral plane. Thus, as zoom lenses of a pair of cameras are adjusted to simultaneously zoom in on an object at a given distance from the cameras, the disparity shift should be adjusted so that the target remains in the neutral plane. This can be accomplished, for example, by linking control of servo 345 which controls camera separation with servo 440 of Figure 4 which controls zooming by, for example, use of a look-up table.

In this disclosure, there is shown and described only the preferred embodiment of the invention, but, as aforementioned, it is to be understood that the invention is capable of use in various other combinations and environments and is capable of changes or modifications within the scope of the inventive concepts as expressed herein.

WHAT IS CLAIMED IS:

1. Apparatus for capturing three dimensional stereo images of a scene comprising:

a left camera and a right camera with parallel optical axes,

means for maintaining spacing between said left camera and said right camera a fixed fraction of a distance to a targeted object.

2. Apparatus of claim 1 in which the fixed fraction is a default value which can be overridden by manual adjustment.

3. Apparatus for capturing three dimensional stereo images of a scene comprising:

a left camera and a right camera with substantially parallel optical axes, and each having substantially identical zoom lenses;

means for adjusting disparity while adjusting focal length of the zoom lenses to hold a location of the neutral plane substantially constant.

4. Apparatus for capturing three dimensional stereo images of a scene comprising:

a left camera and a right camera having substantially parallel optical axes and substantially identical zoom lenses;

means for adjusting disparity while adjusting focal length of the zoom lenses to avoid loss of stereo effect.

5. A method of maintaining disparity of a stereo pair of images within a range which avoids a loss of stereo effect without camera toe in while avoiding vertical shift between corresponding points of a left view and a right view of said stereo pair, comprising:

maintaining the optical axes of a left camera and of a right camera substantially parallel, and

adjusting disparity while adjusting distance to a target object to avoid loss of stereo effect.

6. Apparatus for viewing three dimensional images comprising:

means for shifting one image view with respect to an other image view to control the amount of disparity between corresponding points from the two views and

display means for displaying the one and the other image views so as to form a three dimensional image.

7. The apparatus of claim 6 in which the means for shifting one image view with respect to another includes means for shifting one color plane of said one image view with respect to one or more color planes of said other image view;

8. The apparatus of claim 7 in which the means for shifting one color plane with respect to one or more color planes comprises means for cropping two image planes at different ends by the amount of a desired disparity shift and means for combining the cropped image planes to produce a three dimensional display.

9. The apparatus of claim 7 in which the means for shifting one color plane with respect to one or more color planes comprises means for limiting the read out of certain addresses of each line of image information of each color plane.

10. The apparatus of claim 7 in which the means for shifting one color plane with respect to one or more

color planes comprises a shift register for receiving a line of image data and means for selecting which cell of the shift register is used for shifting the contents of the shift register to an output.

11. Apparatus for capturing three dimensional images comprising:

a left camera and a right camera, each camera having a zoom lens;

b. means for controlling the zoom lenses of each camera so that each lens zooms substantially identical amounts when zooming is used; and

c. storing images from the left and right cameras.

12. Apparatus for controlling disparity of images captured by two different cameras comprising:

a. a first camera and a second camera;

b. means for movably mounting the first camera with respect to the second camera for controlled movement of one camera with respect to another; and

c. means for storing images from the first and second cameras.

13. The apparatus of claim 12 in which the means for movably mounting the first camera with respect to the second camera for controlled movement comprises means for controlling toe-in of one camera with respect to the other.

14. The apparatus of claim 12 in which the means for movably mounting the first camera with respect to the second camera for controlled movement comprises means for controlling horizontal offset of one camera with respect to the other.

15. In three dimensional camera arrangements, apparatus for zooming on a scene comprising;

a. at least a left and a right camera, each camera having a zoom lens;

b. means for controlling the zoom setting of each camera so that each zoom lens zooms the same amount;

c. means for storing images from the left and right cameras.

16. The apparatus for zooming of claim 15 in which the means for controlling the zoom setting of each camera comprises servomechanisms for adjusting a zoom lens of each camera simultaneously.

17. The apparatus for zooming of claim 15 in which each zoom lens further comprises coding indications on an outer ring of the lens and said means for controlling the zoom setting uses said coding indications to determine the amount of zoom.

18. The apparatus for zooming of claim 15 in which each zoom lens further comprises magnetic indications on the lens and said means for controlling the zoom setting uses said indications to determine the amount of zoom.

19. The apparatus for zooming of claim 15 in which each zoom lens further comprises coding indications on an outer ring of the lens and said means for controlling the zoom setting uses said coding indications to determine the amount of zoom.

20. Apparatus for producing three dimensional images captured using a left and a right video camera connected to respective left and right video recorders;

a. means for matching an image from one of the left or right video recorders with the corresponding image of the other video recorder;

b. means for filtering the output of the left video recorder to eliminate blue and green information;

c. means for filtering the output of the right video recorder to eliminate the red information; and

d. means for combining the outputs of each of the means for filtering to produce a three dimensional image.

21. The apparatus of claim 20, further comprising means for shifting information from one of the means for filtering with respect to the output of the other means for filtering.

22. Means for reproducing a three dimensional image from a first and a second digital images stored on a storage medium, comprising:

a. means for decomposing each of said first and second digital images into red, green and blue color planes;

b. means for shifting one color plane of said first digital image with respect to other color planes of said second digital image; and

c. means for combining the shifted color plane of said first digital image with said other color planes to produce a three dimensional image.

23. A method of live monitoring of three dimensional images being captured by first and second cameras to a storage medium comprising:

a. separating the output of each camera into color planes;

b. combining one color plane of said first camera with one or more different color planes from said second camera; and

c. displaying the combined color planes.

24. A method of automatically adjusting an image parameter during creation of a reproduction of a live scene, comprising:

a. placing a small, highly reflective material on a target to be tracked;

b. illuminating said hightly reflective material;

c. using the bright spot created by reflection from said hightly reflective material for calculating target position;

d. adjusting said image parameter based on the calculated target position; and

e. using the image parameter to control apparatus for creating said reproduction.

25. The method of claim 24 in which the image parameter is focus.

26. The method of claim 24 in which the image parameter is disparity.

27. The method of claim 24 in which the image parameter is zoom.

28. A method of moving the apparent position of an object represented as left and right images which together constitute a three dimensional image viewed by a viewer to make the object appear to move toward the viewer or recede away from the viewer, comprising:

a. shifting the position of the left and right images change the disparity to thereby cause the perceived relataive position of the object to move; and

b. combining the shifted images to produce a three dimensional image.

29. A method of creating a three dimensional computer generated animation of an object, comprising:

a. representing said object as a three dimensional wire frame;

b. rendering a surface on said wireframe;

c. creating two color perspective views of said rendered wireframe;

d. separating each of said two color perspective views of said rendered wireframe into 3 color planes;

e. combining a one color plane from one of said views with two other color planes from the other view; and

f. storing the combined color planes as a three dimensional image;

g. moving said object by modifying said wire frame; and

h. repeating steps b through f for as many iterations as desired.

30. The method of claim 29 further comprising the step of displaying sequentially each three dimensional image stored as one image of a three dimensional animation.

31. The method of claim 29 in which the creating two color perspective views of said rendered wireframe includes creating such views in synchronism and with focal lengths utilized for making the views matched.

32. A method of creating a three dimensional computer generated animation of an object, comprising:

a. representing said object as a three dimensional wire frame;

b. rendering a surface on said wireframe;

c. creating one perspective views of said rendered wireframe containing only color information from one

color plane of three color planes used to represent all colors;

d. creating a second perspective view of said rendered wireframe containing color information from the remaining color planes ;

e. combining a color information all three color planes ; and

f. storing the combined color planes as a three dimensional image;

g. moving said object by modifying said wire frame; and

h. repeating steps b through f for as many iterations as desired.

33. The apparatus of claim 11 in which the means for controlling the zoom lenses of each camera includes:

a. individual stepper motors for controlling the zoom of each zoom lens, one zoom lens serving as a master lens and the other serving as a slave lens;

b. a look up table storing calibration data relating to at least one of the zoom lenses; and

c. means setting the degree of zoom for the slave lens so it provides substantially the same amount of zoom as the master lens based upon the contents of said look up table.

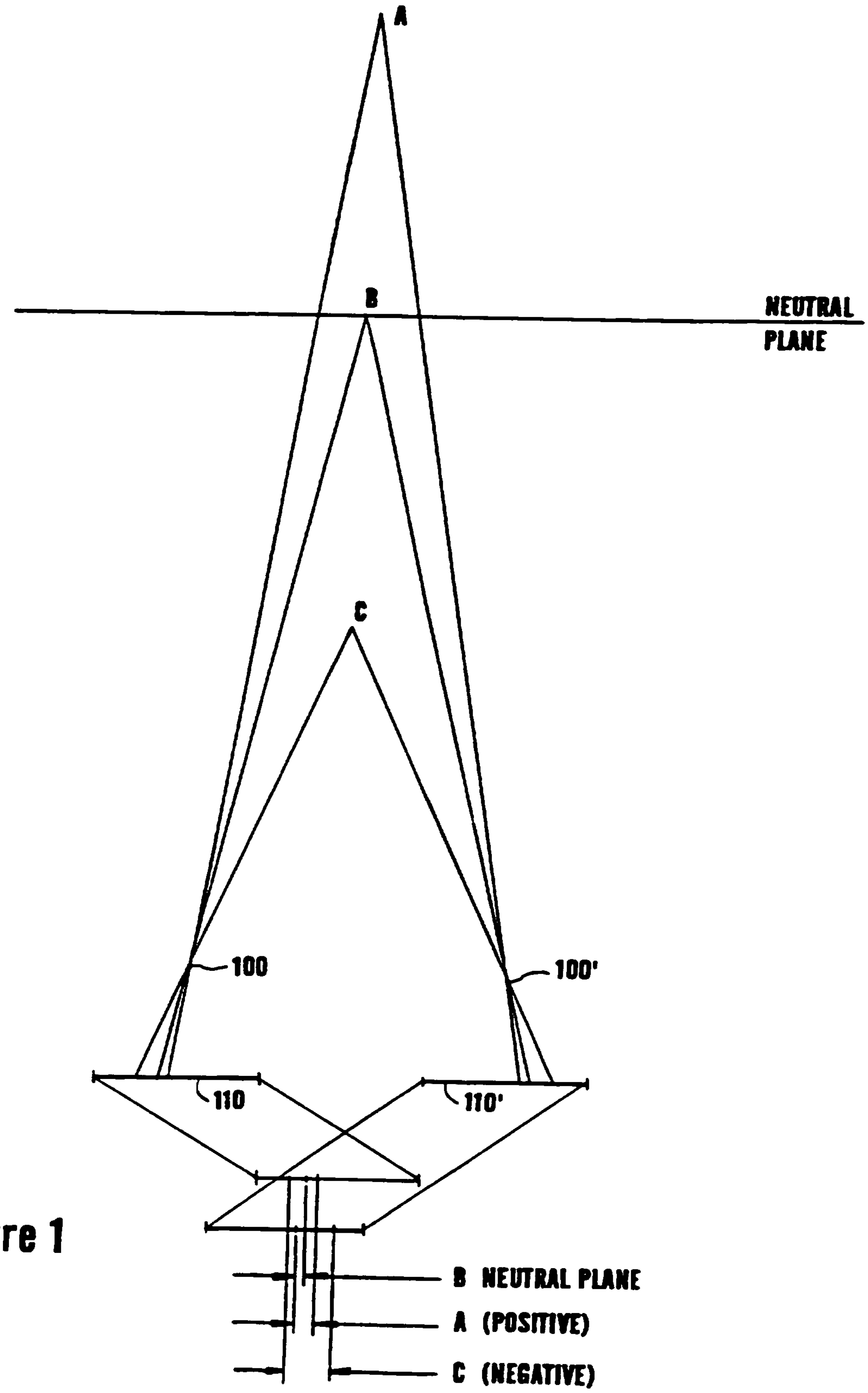

A
B
NEUTRAL PLANE
C
100
100'
110
110'
B NEUTRAL PLANE
A (POSITIVE)
C (NEGATIVE)

Figure 1

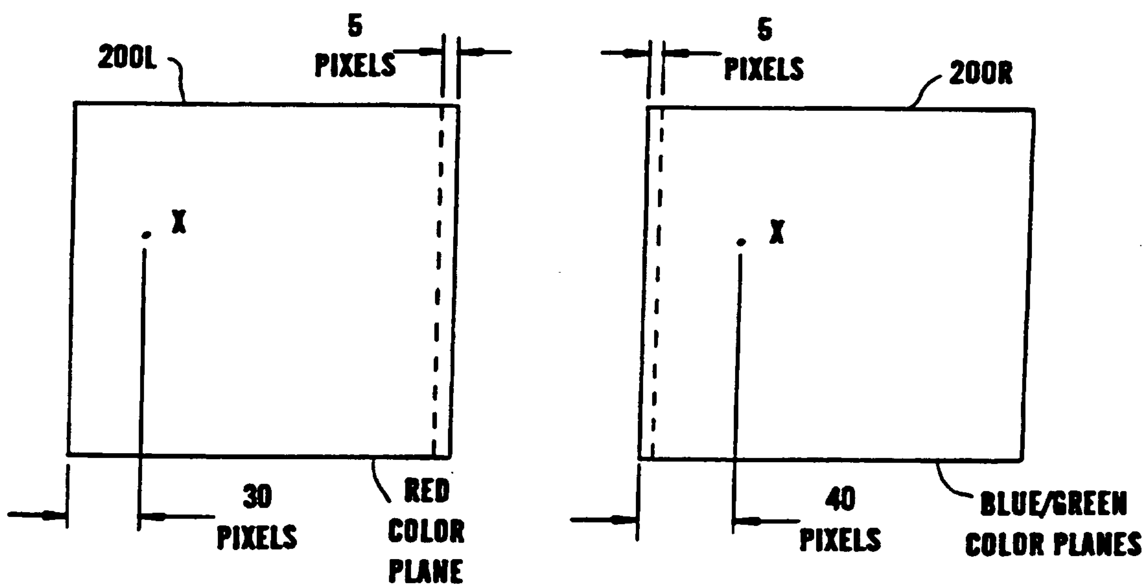

200L
5
PIXELS
5
PIXELS
200R
X
X
30
PIXELS
RED
COLOR
PLANE
40
PIXELS
BLUE/GREEN
COLOR PLANES

Figure 2

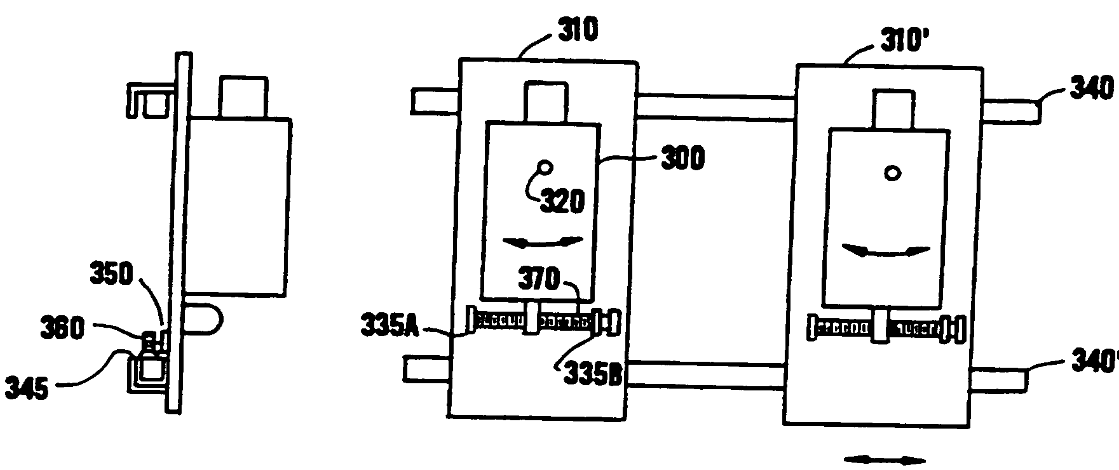



Figure 3

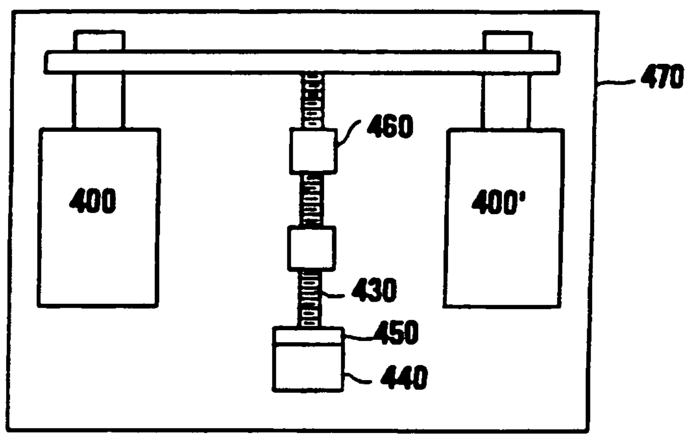



Figure 4

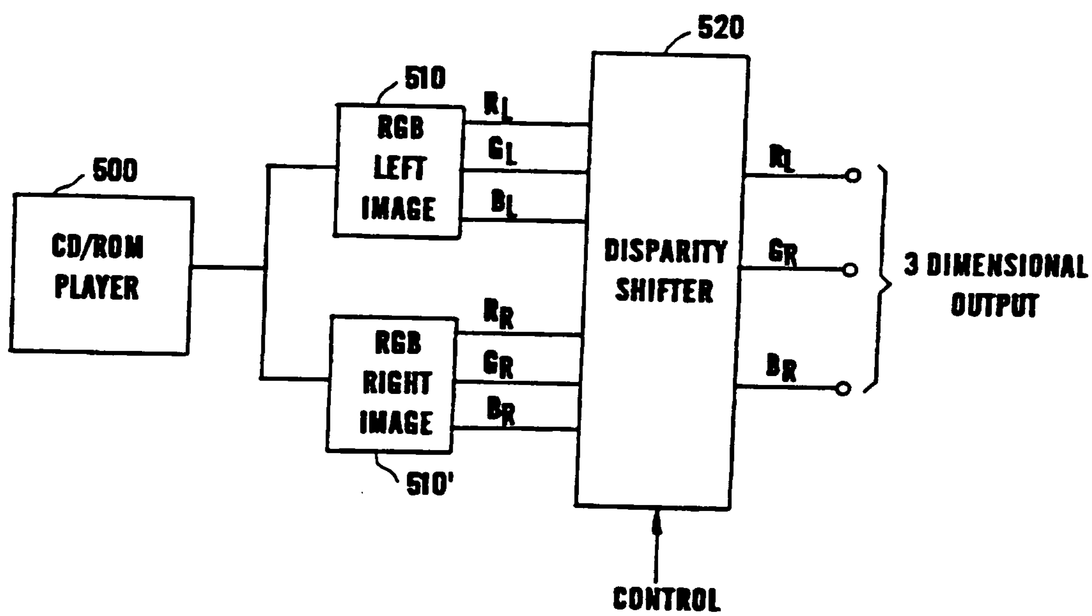
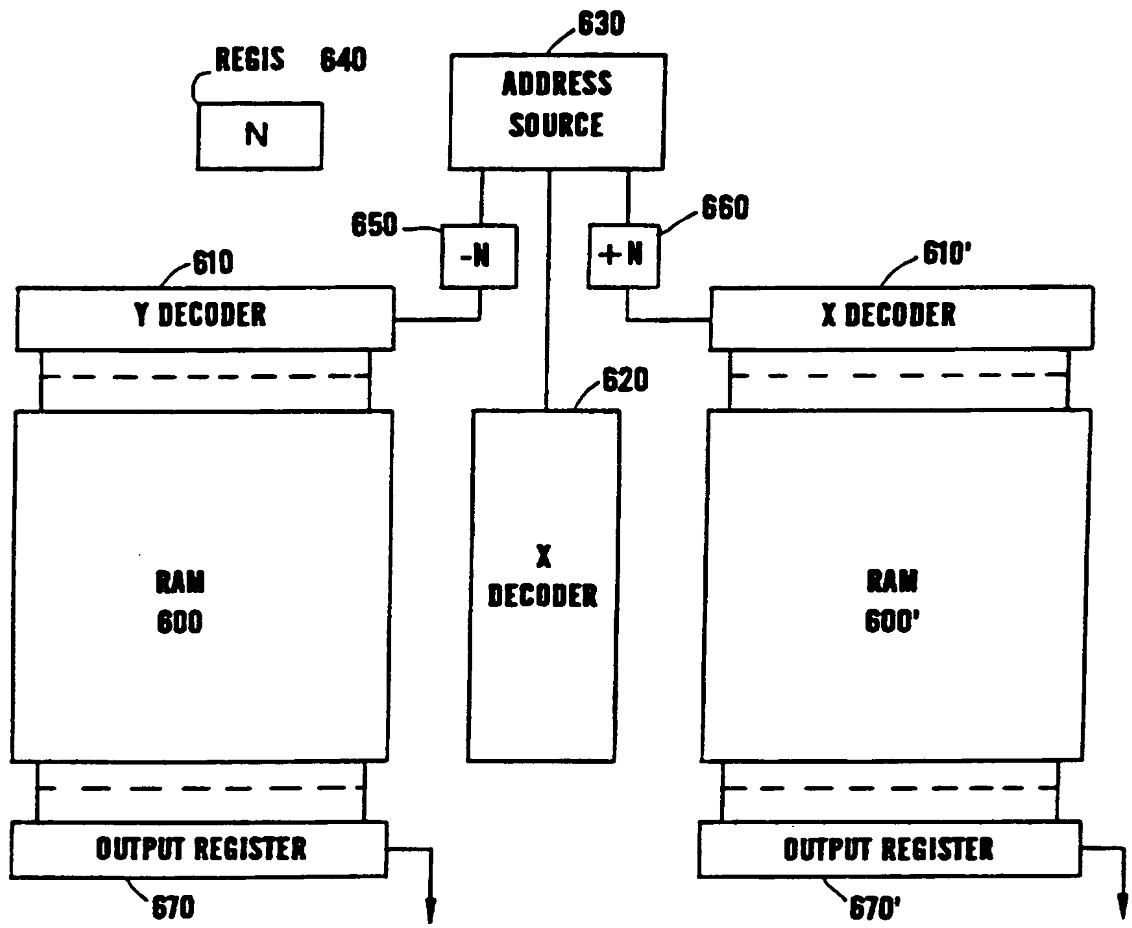

500
CD/ROM PLAYER
510
RGB LEFT IMAGE
$R_L$
$G_L$
$B_L$
RGB RIGHT IMAGE
510'
$R_R$
$G_R$
$B_R$
520
DISPARITY SHIFTER
$R_L$
$G_R$
$B_R$
3 DIMENSIONAL OUTPUT
CONTROL

Figure 5



REGIS 640
N
630
ADDRESS SOURCE
650
-N
+N
660
610
Y DECODER
610'
X DECODER
620
RAM 600
X DECODER
RAM 600'
OUTPUT REGISTER
670
OUTPUT REGISTER
670'


Figure 6

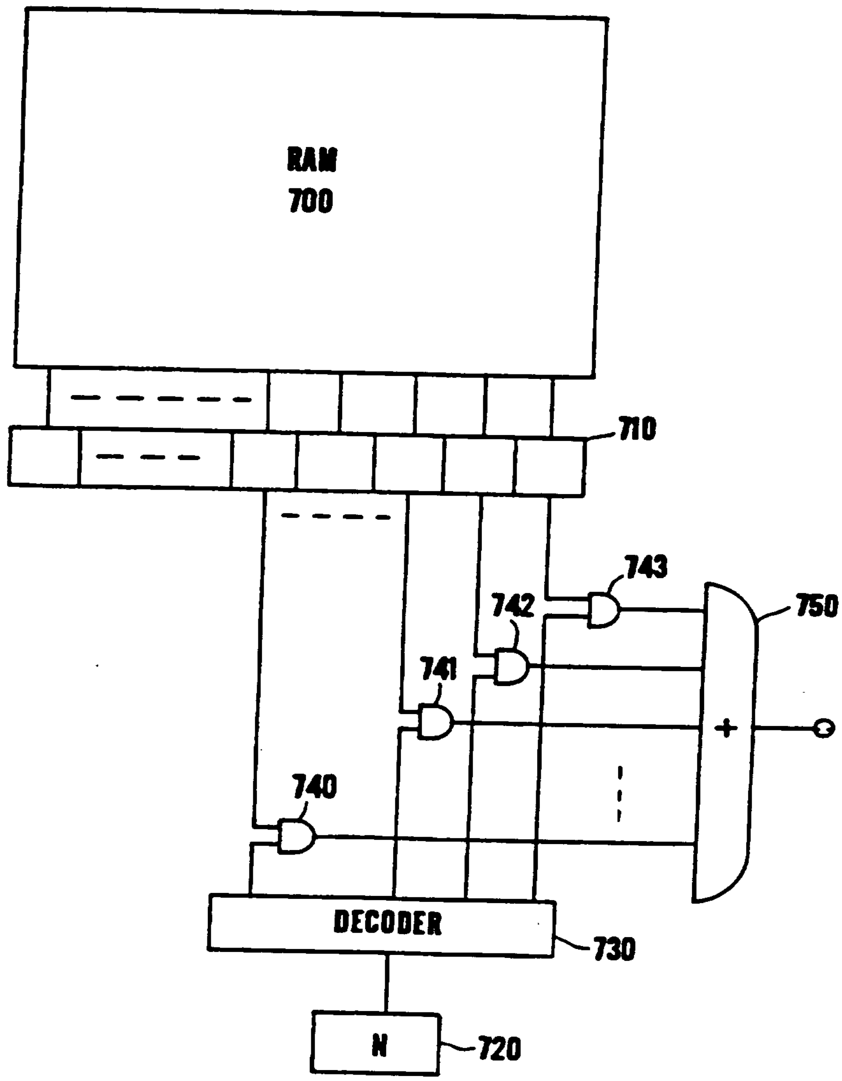



Figure 7

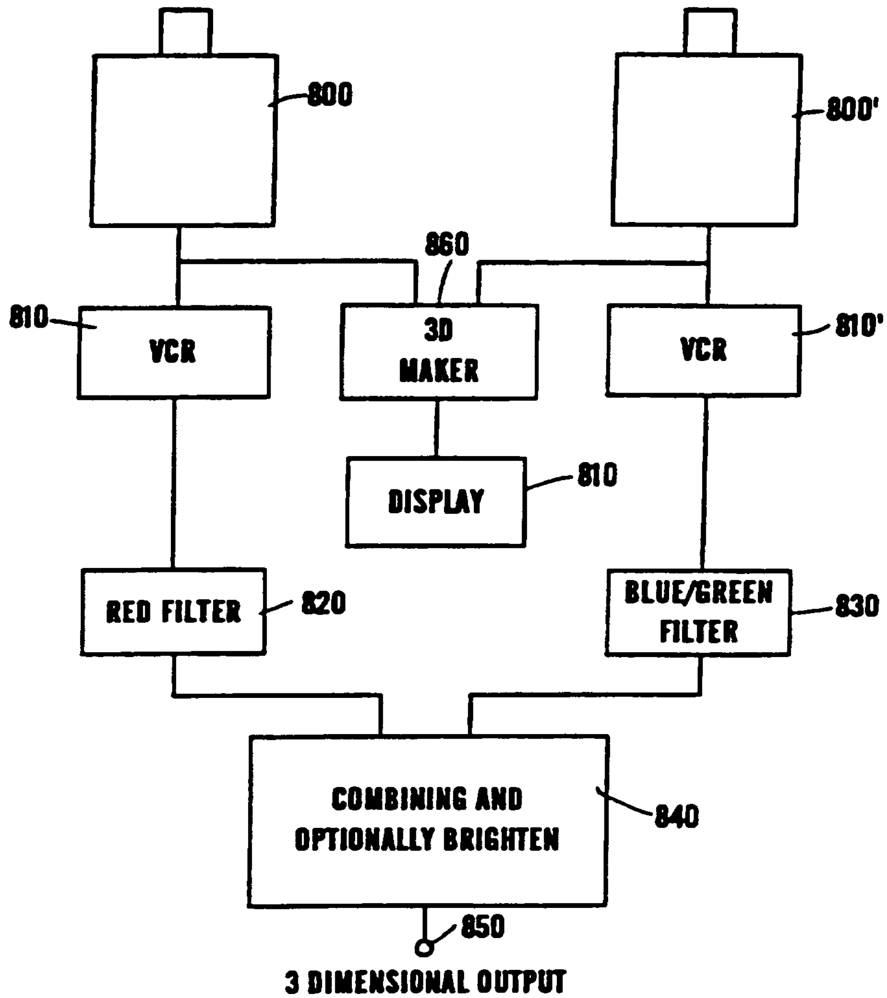

800
800'
860
810
VCR
3D
MAKER
VCR
810'
DISPLAY
810
RED FILTER
820
BLUE/GREEN
FILTER
830
COMBINING AND
OPTIONALLY BRIGHTEN
840
850
3 DIMENSIONAL OUTPUT

Figure 8

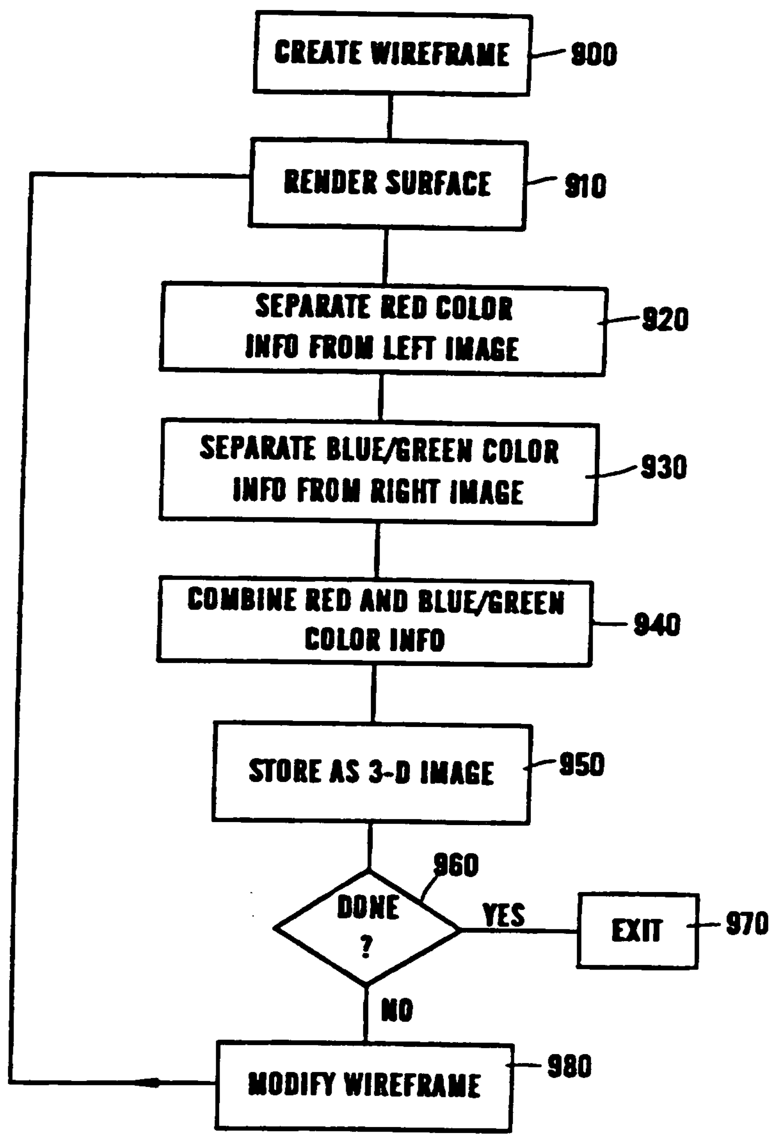

CREATE WIREFRAME
900
RENDER SURFACE
910
SEPARATE RED COLOR INFO FROM LEFT IMAGE
920
SEPARATE BLUE/GREEN COLOR INFO FROM RIGHT IMAGE
930
COMBINE RED AND BLUE/GREEN COLOR INFO
940
STORE AS 3-D IMAGE
950
960
DONE ?
YES
EXIT
970
NO
MODIFY WIREFRAME
980

Figure 9

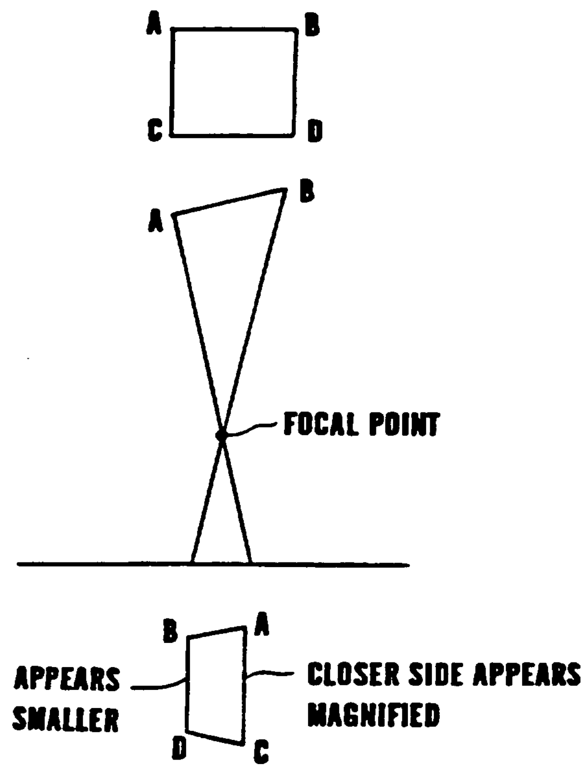

A
B
C
D
B
A
FOCAL POINT
B
A
APPEARS SMALLER
CLOSER SIDE APPEARS MAGNIFIED
D
C

Figure 10

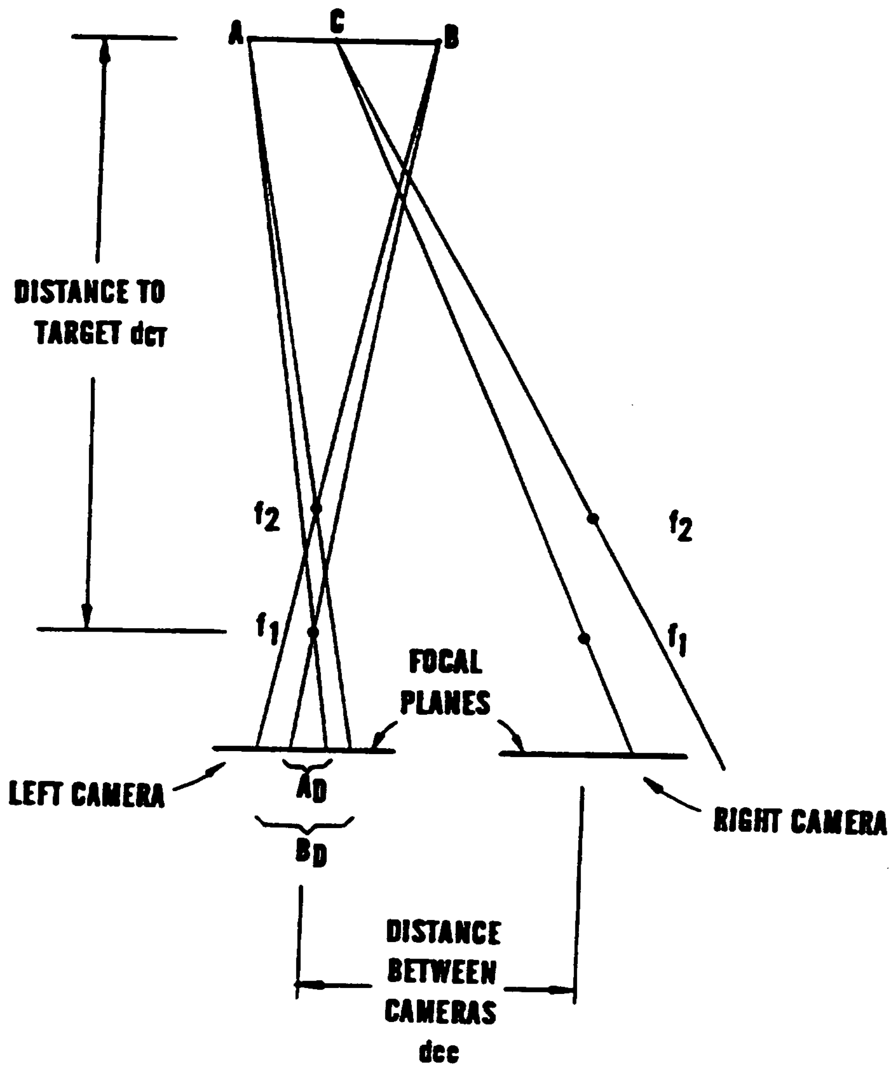

A
C
B
DISTANCE TO TARGET dcT
f2
f1
f2
f1
FOCAL PLANES
LEFT CAMERA
RIGHT CAMERA
AD
BD
DISTANCE BETWEEN CAMERAS dcc

Figure 11

## INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/14414

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :H04N 13/00
US CL :348/47, 60
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 348/47, 42, 43, 50, 58, 59, 60, 77

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | US, A, 4,751,570 (ROBINSON) 14 June 1988, column 3, lines 20-68; figure 2. | 1-5, 11-14, 15-19 |
| Y | US, A, 4,819,064 (DINER) 04 April 1989, column 12, lines 12-68. | 6-10, 22-31 |
| Y | US, A, 5,235,416 (STANHOPE) 10 August 1993, column 4, lines 20-65. | 24-33 |
| Y | US, A, 5,012,351 (ISONO ET AL) 30 April 1991, column 7, lines 9-52. | 20-21 |
| Y | US, A, 4,734,756 (BUTTERFIELD ET AL) 29 March 1988, column 22, lines 13-68. | 6-10 |
| A | US, A, 5,142,642 (SUDO) 25 August 1992, figure 2, elements 5a/5b. | 6-10, 22-31 |

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

14 FEBRUARY 1996

Date of mailing of the international search report

21 MAR 1996

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/14414

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | US, A, 4,999,713 (UENO ET AL) 12 March 1991, figure 13. | 1-19, 32-33 |
| A | US, A, 4,966,436 (MAYHEW ET AL) 30 October 1990, figure 2. | 6-10, 22-31 |
| A | US, A, 4,480,263 (VAN MERODE) 30 October 1984, figure 2a. | 20-21 |